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Compressive strength and failure types of cusp replacing direct resin composite restorations in previously amalgam-filled premolars versus sound teeth

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Short title: *Compressive strength of cusp replacing direct composite restorations*

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Abstract: This study evaluated the fracture resistance of cusp replacing direct resin composite restorations (DCR) in premolars that had been previously filled with amalgam MOD restorations and compared their fracture resistance with those made on sound dentin and intact teeth. Recently extracted human premolars with either MOD amalgam restorations or sound/intact ones were selected for the study. Cavities with cusp reduction were made for the following groups: a) Group 1: DCRs on previously amalgam-affected dentin (n=11) and b) Group 2: DCRs on sound dentin (n=10) and c) Group 3: Intact premolars (n=9). Teeth in Groups 1 and 2 were restored with a 3-step etch and rinse adhesive (Quadrant Unibond) and filled with hybrid composite (Clearfil Photo Posterior). All specimens were thermocycled for 5000 cycles (5-55°C). The buccal cusps of the teeth were loaded until fracture under compression at 45° to the long axis of the teeth in a Universal Testing Machine (1 mm/min). Data (N) were statistically analyzed using one-way ANOVA and Student-t test (alpha=0.01). Intact teeth (Group 3) showed significantly higher fracture resistance (893±196) compared to both restored groups (p<0.01). No significant difference was found between the DCRs made on amalgam-affected dentin (Group 1: 607±166) and sound dentin (Group 2: 588±183) (p>0.01). More than half of the teeth of Groups 2 and 3 showed unrepairable fractures with pulp exposure.

Keywords: Cusp replacement, direct composite restorations, fracture resistance

Introduction

A major advantage of resin composites is that they can be adhesively bonded to enamel and dentin, thus enabling less invasive cavity preparations and strengthening of the tooth-restoration complex. Patients increasingly demand for tooth colored restorations and are aware of possible adverse health reactions. Also, the use amalgam creates an environmental burden that should be reduced drastically. Governmental institutions therefore promote a phasing out or phasing down of the use of amalgam. Because of improved material properties, modern resin composites become viable alternatives to amalgam for clinical use in posterior teeth and resin composites are regarded at an increasing rate as the material of choice for restorations in posterior teeth [1,2].

In general dental practice fracture of cusps in amalgam-restored teeth is a common phenomenon [3,4]. In fractured teeth with mesial-occlusal-distal (MOD) amalgam restorations, restoring only the fractured cusps could be sufficient to provide adequate retention for the remaining restoration and in the tooth. However, when macro-mechanical retention of the remaining amalgam is insufficient or estimated as insufficient for long-term survival of the tooth-restoration complex, also the remaining (MOD) restoration needs to be replaced. For re-restoration of such fractured teeth cusp replacing direct composite resin restorations is a viable treatment option as this method compensates for the lack of macro-mechanical retention, saves tooth substance, reinforces the tooth-restoration complex and it is cost-effective.

Cusp covering direct composite restorations (DCR) demonstrated acceptable results in clinical studies [5,6]. An essential factor in the success of cusp-covering DCRs is the adhesion to the exposed dentin and enamel. In that regard, the effect of compromised dentin after amalgam removal on the bond strength of resin materials is a critical aspect. Limited information dictates lower microtensile bond strength of resin composites to dentin stained by amalgam by-products [7]. Especially in DCR type of restorations, since no mechanical retention is present, the durability of the restoration highly depends on the adhesion to amalgam-affected or sound dentin. Information in this regard will expand the application of DCRs as an integral part of minimal invasive dentistry. When DCRs perform good enough compared to those bonded on sound dentin, then unnecessary removal of amalgam-stained dentin could be eliminated where the latter may sometimes lead to deep preparations and thereby, pulp exposure. Similarly, as a result of high occlusal loads, non-favourable cusp or tooth fractures on teeth restored with amalgam could also be restored by DCRs in a minimal invasive fashion.

The objectives of this study therefore, were to investigate the fracture strength of cusp replacing DCRs in premolars that had been previously filled with amalgam MOD restorations. The first hypothesis to be tested was that DCRs made on amalgam-affected dentin would show lower fracture strength compared to those made on sound dentin. The second hypothesis was that DCR restored teeth would show lower fracture strength than intact teeth.

Materials and Methods

Specimen preparation

Maxillary intact premolars and those with MOD amalgam restorations were obtained from a pool of recently extracted teeth that were stored in 0.1% thymol solution. Tissue remnants were removed with a scaler (H6/H7; Hu-Friedy, Chicago, IL, USA). Teeth having MOD amalgam restorations with a clinical lifetime of several years, absence of primary or secondary caries and absence of fractures were selected for Group 1. After removal of amalgams, teeth with cement bases and teeth with cracks in tooth substance before or after cavity preparation were eliminated. Only the teeth were selected where the outline of the amalgams did not exceed the cemento-enamel junctions (CEJ). For Groups 2 and 3, intact teeth with absence of caries in dentin, restorations and fractures were selected.

Group 1: This group consisted of premolars (n=11) with MOD amalgam restorations. Existing amalgam was removed with diamond burs (Rondomant 233/010, Heraeus Kulzer, Hanau, Germany) using high-speed hand piece under water coolant. Corrosion material at the amalgam-dentin interface and softened dentin was removed with round tungsten carbide burs (Komet H1S 012, 014 and 018, Brasseler, Lemgo, Germany) until dentin felt hard with a blunt explorer, and dentin was not stained until approximately 1 mm below cavity margins. Stained but hard central dentin was left in place. Buccal cusps were ground down from the axio-pulpal line-angle on to the dentino-enamel junction in order to simulate cusp fracture. A bevel was prepared on enamel outline (Fig. 1a).

Group 2: This group consisted of sound premolars (n=10) with no signs of decay. MOD cavities were prepared initially and and buccal cusps were ground down congruent to the specimen preparation described in Group 1 (Fig. 1b).

In both Groups 1 and 2, it was made sure that the lingual cusps were at least 2 mm thick in bucco-lingual direction.

Group 3: In this group, non-prepared sound premolars (n=9) without any cavity preparation, having intact cusps acted as the control group (Fig. 1c).

Restorative procedures

The brands, manufacturers, chemical compositions and batch numbers of the materials used for the restorations are listed in Table 1.

Teeth in Groups 1 and 2 were restored to their original contour using transparent moulds that had been prepared prior to cavity preparation. The cavities were conditioned using a 3-

step total etch technique. Enamel margins and dentin were etched simultaneously with 37% phosphoric etching gel (Ultra-Etch, Ultradent, South Jordan, USA) for 20 s, rinsed with water spray for about 5 s. Then, primer (Quadrant Unibond Primer, Cavex Holland, Haarlem, The Netherlands) was applied for 20 s using microbrush, gently air-blown for 2 s and adhesive resin (Quadrant Unibond Sealer, Cavex Holland) was applied, air-thinned and photo-polymerized for 20 seconds using an halogen device (Demetron LC, Kerr, Orange, CA, USA). A midifilled hybrid composite (Clearfil Photo Posterior, Kuraray, Tokyo, Japan) was incrementally applied in layers of maximum 2 mm. Each layer of resin composite was photo-polymerized for 40 s). The output of the polymerization unit was >500 mW/cm^2, verified by a radiometer (Demetron LC, Kerr, Orange).

For all teeth to be restored, individual transparent moulds had been fabricated prior to cavity preparation. These moulds enabled building restorations in original anatomic contour. Restorations were finished with fine diamond burs, tungsten carbide burs and rubber points.

The roots of the specimens were embedded in polymethylmethacrylate (Autoplast, Candulor, Wagen, Switzerland) up to 1 mm below the cemento-enamel junction. All specimens were then artificially aged in a thermocyling device (Willytec, Gräftelfing, Germany) for 5000 cycles (5°C to 55°C; dwell time in each bath: 30 s; transfer time: 5 s).

Embedded teeth were mounted in the jig of the Universal Testing Machine (Zwick Roell Z2.5 MA 18-1-3/7, Zwick, Ulm, Germany) and buccal cusps were loaded under compression until fracture at 45° angle to the long axis of the teeth at a crosshead speed of 1 mm/min (Figs. 2a-b).

Failure analysis

Failure sites were initially observed by naked eye under a light source and classified as follows: Type 1: Small cusp fracture of the intact tooth, Type 2: Vertical cusp fracture of the intact tooth, Type 3: Small fracture of the restored cusp, Type 4: Vertical fracture of the restored cusp extending to the cervical area, Type 5: Vertical fracture of the restored cusp including small portion of the root, Type 6: Vertical fracture of the restored cusp including larger portion of the root, Type 7: Detachment of the restoration from the dentin walls and including larger portion of the root fracture, Type 8: Root fracture only.

Statistical analysis

Data were analyzed using a statistical software package (SPSS Software V.20, Chicago, IL, USA). Kolmogorov-Smirnov and Shapiro-Wilk tests were used to test normal distribution of the data. As the data were normally distributed, 1-way analysis of variance (ANOVA) and Student t-tests were applied to analyze possible differences between the groups. $P<0.01$ was considered to be statistically significant in all tests.

Results

Mean fracture resistance of intact teeth (Group 3) was significantly higher (893±196) than both restored groups ($p<0.01$) (Table 2). No significant difference was found between the DCRs made on amalgam-affected dentin (Group 1: 607±166) and sound dentin (Group 2: 588±183) ($p>0.01$).

For unrestored intact teeth (Group 3) all failures were repairable depicted as Type 1 and 2. More than half of the teeth of Group 1 (7 restorations, 63.3%) and Group 2 (8 restorations, 70%) showed failures involving root fracture with pulp exposure (Types 5,6,7) (Table 3).

Discussion

This study was undertaken in order to find out whether DCRs made on amalgam-affected dentin would present inferior fracture resistance compared to those made on sound dentin.

Based on the results of this study, since DCRs made on amalgam-affected or sound dentin presented no significant difference in terms of mean fracture strength, the first hypothesis could be rejected. However, intact teeth presented significantly higher mean fracture strengths compared to both DCR groups, yielding to acceptance of the second hypothesis.

Complete cusp fracture of posterior teeth, especially those restored with Class II amalgam restorations, is commonly encountered in dental practice. The vast majority of cusp fractures in teeth without endodontic treatment occurs above the CEJ indicating that they could be restored. Instead of crown restorations, DCRs are considered tissue saving and aesthetic treatment options and also more cost-effective compared to their indirect resin composite or bonded ceramic counterparts [8].

Considering direct and indirect resin composite restorations, controversial results are available. While some studies reported higher fracture resistance for direct [9] and indirect resin composite restorations [10], other studies revealed no significant differences [11,12]. With regard to the failure mode, catastrophic fractures were reported more frequently for direct restorations [12] although clinically no significant differences in survival rates of direct and indirect resin composite restorations were observed [13,14]. For adhesive restorations replacing cusps, both direct and indirect techniques are adequate to restore morphology and function but long-term clinical data are not available to date [15].

As retention of DCR restorations depends on the adhesive capacities of the materials used to a great extent, several options are suggested to increase the retention. In-vitro load tests indicated that an additional cervical shoulder preparation does not improve the fracture strength of DCRs as long as some retentive form is present [16]. Furthermore, it was reported that capping of the remaining sound cusp increased the fracture resistance of DCRs [6]. The present study did not compare the fracture resistance of direct and indirect resin composite restorations as the direct options are more cost-effective and could be accomplished in one session.

In this investigation, the results obtained were greater than physiological mastication forces in the posterior region (300 N). Stress applied during mastication may range between 441 N and 981 N, 245 N and 491 N, 147 N and 368 N, and 98 N and 270 N in the molar, premolar, canine, and incisor regions, respectively [4]. A restoration should be able to withstand stress to approximately 500 N in the premolar region and 500 N to 900 N in the molar region to endure the pathological mastication forces in the posterior region. The results of the present study are lower than in a recent report, where no aging was performed [8]. The difference could be attributed to aging through thermocycling procedure prior to loading. Furthermore, even though attempts are made to select teeth with similar size, high standard deviations in such studies are typical. This could be partially due to the varied age of the extracted teeth. Teeth in groups 1 had lower mean age than teeth in groups 2 and 3, as the latter were teeth which had been extracted for orthodontic reasons in younger individuals in general.

It was also reported in the literature that the cusp covering direct composite restorations showed unrepairable fractures of the tooth-restoration complex under load [6]. In clinical situations, the prognosis after restoration failure depends on the location of the fracture. A tooth with a fracture below the CEJ is difficult or sometimes impossible to restore [17]. The failure types were similar to that of the previous study, namely failures were restorable for unrestored, intact teeth (Group 3), while more than half of the teeth of DCRs showed fractures with pulp exposure.

After removal of amalgam restorations, dentin tissue is generally characterized by dark staining underneath the amalgam. This stain is not limited to the interface but diffuses into dentin in pulpal direction. Corrosion products from amalgam are held responsible for this staining. It has been also reported that Sn and Zn ions from the amalgam penetrates into the dental tissues [7]. However, information on the effect of amalgam staining on adhesive capability of resin composites is limited where lower bond strengths of resin composites to dentin stained by amalgam were noted [7].

The materials chosen for the study were similar to those used in a recent clinical study where clinical longevity of extensive DCRs in amalgam replacement was reported after 3.5 years of follow-up [18]. Although this duration may be considered not long-term, four failures were observed due to fracture (n=1), endodontic complications (n=2) and inadequate proximal contact (n=1). Failures were related neither to inadequate adhesion nor to secondary caries with a cumulative survival rate of 96.6%. Although, there was no randomization made in that clinical study, it can be stated that the DCRs made on amalgam-affected dentin could survive at least 3.5 years. It should be noted that premolars due to their anatomy of the two cusps might be more prone to fracture. Thus, in that respect, the experimental design may reflect a more severe clinical scenario. Nevertheless, long-term reports of clinical studies are needed to verify whether amalgam-affected dentin would be a suitable substrate for bonded DCRs.

During clinical function, intermittent compressive forces are at least as challenging as shear stresses and may result in repairable or unrepairable cusp fractures. The similar incidence of the unrepairable fractures of cusp replacing direct composite restorations made on both amalgam-affected and sound dentin indicated that adhesion to dentin was not compromised when it was stained from amalgam ions.

Conclusions

From this study, the following could be concluded:

1. Cusp replacing direct resin composite restorations in previously amalgam filled premolars showed similar fracture resistance compared to those that were made on sound dentin. Both restoration types presented significantly less fracture resistance compared to unrestored, intact premolars.

2. Compared to intact teeth, cusp replacing direct resin composite restorations both on amalgam-affected and sound dentin presented more unrepairable failures after maximum loading.

Clinical Relevance

Cusp replacing direct resin composite restorations could be an alternative minimal restoration procedure for previously amalgam-filled premolar when fracture resistance is considered, providing that failure types were not favourable. Thus, more clinical information is needed for their durability in stress bearing areas.

Conflict of interest

The authors did not have any commercial interest in any of the materials used in this study.

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Captions to tables and figures:

Tables:

Table 1. The brands, manufacturers and chemical compositions of the materials used for the restorations and their application protocol.

Table 2. Mean compressive strength and standard deviation. *Same superscript letters indicate no significant difference ($p>0.05$).

Table 3. Frequencies of failure modes (percentages) for each experimental group. Type 1: Small cusp fracture of the intact tooth, Type 2: Vertical cusp fracture of the intact tooth, Type 3: Small fracture of the restored cusp, Type 4: Vertical fracture of the restored cusp extending to the cervical area, Type 5: Vertical fracture of the restored cusp including small portion of the root, Type 6: Vertical fracture of the restored cusp including larger portion of the root, Type 7: Detachment of the restoration from the dentin walls and including larger portion of the root fracture, Type 8: Root fracture only.

Figures:

Figs. 1a-c. Representative images of the specimens from Group 1: Premolars with pre-existing amalgam-affected dentin, Group 2: Premolars with sound dentin and Group 3: Intact premolars (control).

Figs. 2a-b. Specimen positioned in the universal testing machine where load was applied **a)** to the buccal cusp under compression at 45° angle to the long axis of the teeth **b)** until fracture of the cusp in intact tooth or the cusp coverage resin composite restoration.

Tables:

Materials and Manufacturer	Type	Chemical Composition	Application Protocol
Ultra-Etch (Ultradent, South Jordan, USA)	Etching gel	35% phosphoric acid	Apply the etching gel for 20 s Rinse with water spray for 5 s Gently air-dry for 5 s
Quadrant Unibond Primer (Cavex Holland, Haarlem, The Netherlands)	Dentin primer	Methacrylate-based monomers 39.6 w%, carboxylic acid based monomer 6.3 w%, polymerization catalysts 0.3 w%, solvents 53.8 w%	Apply the primer to the surface and rub it for 20 s Gently air-dry for 5 s until the solvent evaporates completely
Quadrant Unibond Sealer (Cavex Holland)	Adhesive resin	Methacrylate-based monomers 69.4 w%, carboxylic acid based monomer 4.3 w%, polymerization catalysts 0.5 w%, silica and silicate glass fillers 25.8 w%	Apply the adhesive resin Gently blow the excess adhesive resin Photo-polymerize the adhesive for 20 s
Clearfil PhotoPosterior (Kuraray Dental, Tokyo, Japan)	Resin composite	Filler amount: 86 w%, 71 vol% Filler type: silica and quartz Mean filler particle size: 4 μm Monomer: bis-GMA	Apply the composite in 2 layers Photo-polymerize each layer for 40 s

Table 1. The brands, manufacturers and chemical compositions of the materials used for the restorations and their application protocol.

	Compressive strength (±SD) (N)
Group 1	607 ± 166^{a}
Group 2	588 ± 183^{a}
Group 3	893 ± 196^{b}

Table 2. Mean compressive strength and standard deviation. *Same superscript letters indicate no significant difference ($p>0.05$).

	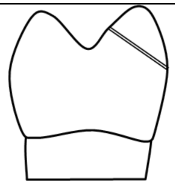	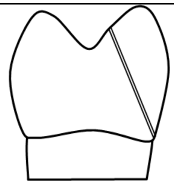	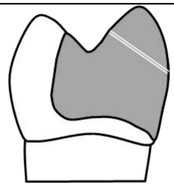	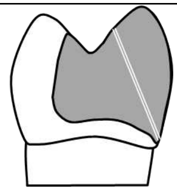	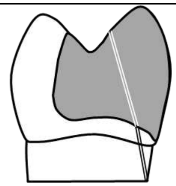	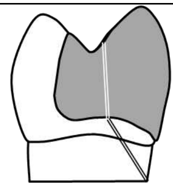	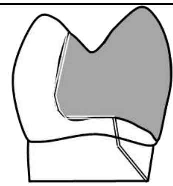	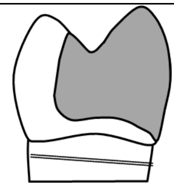
Groups	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 5**	**Type 6**	**Type 7**	**Type 8**
Group 1 n=11 (%)	0 (0)	0 (0)	0 (0)	4 (36.4)	0 (0)	2 (18.2)	5 (45.4)	0 (0)
Group 2 n=10 (%)	0 (0)	0 (0)	1 (10)	0 (0)	1 (10)	3 (30)	4 (40)	1 (10)
Group 3 n=9 (%)	4 (44.4)	5 (55.6)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table 3. Frequencies of failure modes (percentages) for each experimental group. Type 1: Small cusp fracture of the intact tooth, Type 2: Vertical cusp fracture of the intact tooth, Type 3: Small fracture of the restored cusp, Type 4: Vertical fracture of the restored cusp extending to the cervical area, Type 5: Vertical fracture of the restored cusp including small portion of the root, Type 6: Vertical fracture of the restored cusp including larger portion of the root, Type 7: Detachment of the restoration from the dentin walls and including larger portion of the root fracture, Type 8: Root fracture only.

Figures:

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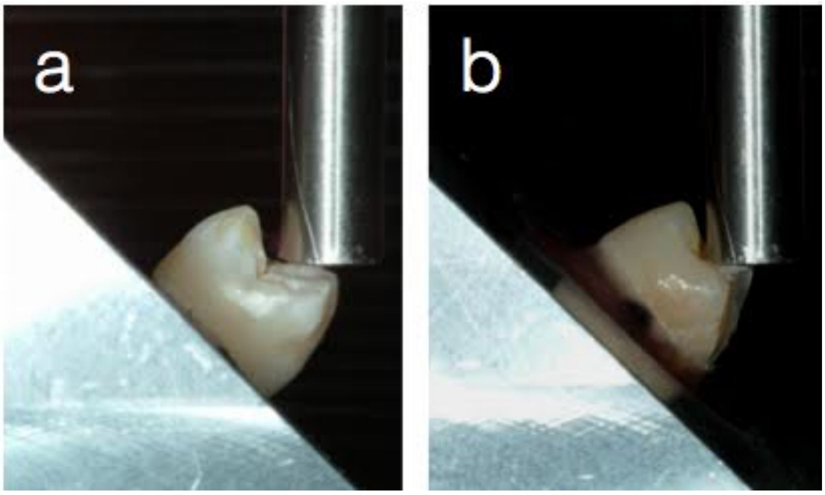

Figs. 2a-b. Specimen positioned in the universal testing machine where load was applied **a)** to the buccal cusp under compression at 45° angle to the long axis of the teeth **b)** until fracture of the cusp in intact tooth or the cusp coverage resin composite restoration.